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GENETIC AND EPIGENETIC SHAPING OF COGNITION – PREREQUISITES OF CULTURAL EVOLUTION

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Before entering the discussion of the evolution of our brains and the options for their epigenetic shaping I consider it appropriate to begin with an epistemic caveat. To the best of my knowledge there is consensus among neurobiologists that all mental phenomena including the highest cognitive functions are the product of neuronal processes. Likewise, social realities such as value systems and moral judgments are considered to be the products of interactions among human beings endowed with brains, the cognitive abilities of which allowed for the initiation of cultural evolution. If one accepts this position it follows that we can only perceive, imagine and comprehend what the cognitive abilities of our brains allow us to seize. Because brains – just as other organs – are the product of evolutionary adaptation, this implies that our cognitive abilities are with all likelihood constrained. Our brains are optimized to secure survival and reproduction in the narrow segment of the world in which life evolved. Coping with the highly specific challenges of an insecure and purely predictable world requires adoption of pragmatic heuristics that differ most likely from the cognitive strategies needed to assess a hypothetical 'objective' truth. Numerous experiments on perceptual illusions illustrate that such is indeed the case. Thus, the sobering conclusion seems to be inevitable that our cognitive abilities are likely to be highly constrained and idiosyncratically adapted to only a very small sector of the world. The world, as unravelled by scientific investigation, extends from infinitely small to infinitely large dimensions. Life, however, has evolved only within a narrow range that extends from micrometers to a few metres. Processes at this mesoscopic scale are dominated by the laws of classical physics and most of the dynamics that life has to cope with are linear. At this scale it makes sense to define states of matter as liquid, solid or gasous, to define space and time as separate categories, and to distinguish between cause and effect. Our sensory systems extract in a highly selective way a few signals from our environment that we then experience as light, temperature, vibrations, sound, smells and tastes. Some of these sensory categories reflect an arbitrary subdivision of physical continua. Thus, we classify electromagnetic radiations with wave lengths between 400 and 700 nm as light and those with longer wave length as heat. To us these categories appear as natural properties of the world and even though we perceive only very narrow spectra of the available physical and chemical signals in our environment, we experience the world as coherent and continuous – a convincing example of the constructive nature of our perception.

Because our cognition has adapted to a narrow range of the mesoscopic world, it is difficult for us to develop intuitions for phenomena at other scales. Our intuition of objects is meaningless in the world of quantum physics just as our concept of causality and our intuition of space and time does not hold for the putative structure of the universe. We tend to believe that the rules and concepts that we infer from the mesoscopic world can be extrapolated to all the other dimensions but there is no guarantee that this is actually the case. It must even be considered that the way in which we reason and draw conclusions is a specific adaptation to the processes at the mesoscopic scale and perhaps not generalizable. Thus, it is very likely that there are natural boundaries to what we can perceive, imagine and understand. Where these limits are and what is concealed behind, will in principle remain unknown. There is, thus, ample space for metaphysics and belief, constrained only be what is actually known.

The constructivistic nature of perception and the sources of knowledge

A large body of psychophysical evidence and neurobiological data indicate that perceiving is essentially a constructive process by which the brain attempts to interpret the sparse sensory signals conveyed by the various sensory organs on the basis of a huge amount of *a priori* knowledge (priors) that is stored in the functional architecture of the brain. What we perceive and how we perceive is by and large determined by context dependent expectancies and stored knowledge about the world. This raises the question of where the knowledge required for the construction of our percepts is derived from. Neurophysiological evidence indicates that knowledge and the rules for its application reside in the functional architecture of the brain. The term ‘functional architecture’ stands for the way in which nerve cells in the brain are interconnected with each other. Unlike in computers that are often erroneously cited to explain the functioning of nervous systems, there are no structurally and functionally different subsystems in the brain that could be considered as central processors and the various storage devices such as memories for data and programs. In the brain there are only neurons, and connections and processing as well as storage functions are accomplished within the same networks. All computations are determined by the functional architecture of these networks. What matters is which neurons are interconnected, whether these connections are excitatory or inhibitory and whether they are strong or weak. The setting of these variables is also the basis of all the knowledge that is stored in the brain. Thus, the search for the sources of knowledge is reduced to the question of which factors specify the functional architectures of brains.

The most important of these factors is beyond any doubt evolution. Through evolutionary selection brain architectures have evolved which contain the knowledge and the application programs that the organism needs in order to cope effectively with the challenges of its environment. In this sense evolution can be considered as a cognitive process. Through adaptation of brain architectures to the requirements of survival in specific biotops knowledge about the world is acquired, stored in the genes and made available for the control of adapted behavior every time a new brain develops. The knowledge acquired through this process is of course implicit. We do not know that we have it because we were not around when it was acquired. Therefore, this knowledge serves as unconscious priors that determines all subsequent cognitive processes. An important consequence is that perceptions based on these implicit priors have the quality of being objective, unreducible and not relativatable. They are taken as representing undisputable truth.

Another important source of knowledge is developmental shaping of brain architectures addressed also as developmental imprinting. The human brain develops structurally until around age 20. This developmental process is characterized by a continuous making and breaking of connections whereby the selection of connections that are to be consolidated is guided by neuronal activity and hence by experience and interaction with the environment. This developmental process leads to a substantial modification and refinement of the genetically specified architecture of brains and thereby installs further knowledge in the brain – this time knowledge derived from interaction with the actual environment in which the organism evolves. Much of this knowledge is also implicit. Brain structures that support episodic memories develop only years after birth which leads to the phenomenon of childhood amnesia. Children up to the age of about 4 years learn about the world but they keep no trace of the context in which they have learnt. They know but they do not know where their knowledge comes from. This is why early acquired knowledge – just as evolutionary knowledge – is implicit, serves as a source of unconscious priors for perception and thereby nourishes convictions that cannot be put to question.

This is not so for knowledge acquired through normal learning processes that begin once episodic memory functions become available and that persist throughout the entire life span. Knowledge acquired through this mechanism is explicit. Subjects are usually aware of having acquired the respective contents by experience and remember the context in which acquisition has taken place. Once brain development has come to an end, further learning is based on activity dependent modifications of the efficiency of existing connections and these changes are brought about by lasting modifications of the molecular machinery that mediates communication among nerve cells, i.e. synaptic transmission. These changes also go along with structural alterations but these are resolvable only at the ultra-structural level.

The layout of the functional architecture of brains is thus determined essentially by three factors, evolutionary adaptation, epigenetic shaping during postnatal brain development and normal learning processes. The resulting architecture in turn determines the various sensory categories according to which we classify sensory signals, the criteria for the definition of objects, the rules according to which brains detect contingencies in the outer world and form associations and finally, the way in which we reason, make inferences and assign values.

The following two figures illustrate the extent to which the *a priori* knowledge stored in the architecture of our brains determines the way in which we perceive.

The object in Figure 1 (see p. 611) is a mold used to produce candies. On the left side one sees the front aspect of the mold with the concavities and on the right the rear side with the corresponding convex protrusions. In reality, both pictures show the front aspect, but one picture is rotated by 180°. The reason for these very different perceptions is that the brain makes the *a priori* assumption that light comes from above. In this case contours that have the shadow above need to be interpreted as concave and those with the shadow below as convex. Thus, an implicit assumption determines what we perceive. Somehow this assumption is implemented in the processing architecture of the visual cortex but we are not aware of it.

Another even more striking example is shown in Figure 2 (see p. 611). It is hard to believe, but surfaces A and B have exactly the same luminance and this can be verified by covering all squares except A and B with white paper. The squares A and B appear as different because the brain sees the shadow that is caused by the cylinder on the right. Even though the amount of light reflected from surfaces A and B and impinging on the retina is exactly the same, the brain interprets the brightness of the two surfaces as different because it infers the following: given that there is a shadow, surface B must be brighter than surface A which has no shadow on it, in order to reflect the same amount of light. Thus, the brain 'computes' the inferred brightness of the surfaces but we are not aware of these computations. We just perceive the result and take it as real, i.e. we see B much brighter than A. One could spend hours with the demonstration of examples which indicate that the brain is generating inferences that we are not aware of, that it is permanently reconstructing the world according to *a priori* knowledge and that we, as perceiving subjects, have to take for granted what the system finally offers us as conscious experience. It is important to emphasize that this is not only the case with specially designed psycho-physical experiments but it is an essential feature of all our perceptual processes. We perceive the result of complex computational operations, and because we are unaware of both the priors and the rationale on which these interpretations are based, we tend to take for granted what we see. We do not realize that our percept is the result of complex computations that are based on assumptions and have difficulties to accept that what appears to be so evident and an invariable property of the perceived object is actually the result of a highly inferential and constructive operation.

The following Gedankenexperiment is meant to illustrate the adaptive value of such perceptual inferences. Imagine that red berries with a specific hue constitute a major food source and that red berries with a slightly different colour are poisonous. It is thus imperative to distinguish between the two sorts of berries and to be able to do this irrespective of daytime. The problem is that the spectral composition of sunlight is radically different in the morning, at noon and in the evening. Accordingly, the spectra reflected by the two kinds of berries differ at different times of the day and it may well be that the spectra of the poisonous berries produced by the morning light resemble the spectra produced by the good berries at noon. Thus, the only way to assure the distinction between the two at any time of the day is to interpret the reflected spectra as a function of the actual spectrum of the sunlight. The latter cannot be measured directly but it can be inferred from the comparison of spectra reflected from familiar objects and *a priori* knowledge of their likely colour. Thus, by comparing the color of leaves, barks, rocks, the clouds etc. the system can estimate the spectral composition of the illuminating light source (the sun), take this into account when interpreting the spectra reflected from the two types of berries and only then compute the hue of the colour that is actually perceived. Through this complicated operation it can be assured that the good berries are perceived as having the same colour irrespective of illumination conditions. This is but one of a large number of examples which illustrate that what we perceive and interpret as invariant properties of objects is actually the result of a highly inferential and constructive process. Furthermore, these examples explain why it is advantageous for organisms to base their perception on *a priori* knowledge and pragmatic heuristics rather than perceiving the absolute, unprocessed values of the signals provided by our sensors that transform physical or chemical stimuli into amplitude modulated neuronal activity.

Causes and effects of cultural evolution

Because most of the priors that determine our perception of the world around us have been acquired during evolution we share them with the animal kingdom. Non-human primates for example but also members of other species such as cats, dogs and even insects make the same inferences and thus perceive the world in similar ways. There are, however, also important differences and these result from the fact that only human brains are exposed during their development to realities that were absent during biological evolution that has shaped our brains as well as those of animals – realities that are the product of cultural evolution. This raises two related questions: what are the cognitive abilities that allowed homo sapiens to initiate the process of cultural evolution and what are the consequences of the epigenetic shaping of human brains by their exposure to socio-cultural realities?

Over the last decades, a number of cognitive functions have been identified that are apparently not found in our nearest neighbors, the great apes, and thus with all likelihood are responsible for the initiation of cultural evolution. One of these functions is the ability to generate a theory of mind, to imagine what goes on in the mind of the respective other when she/he is exposed to a particular situation but does not signal through any perceivable signs what her/his thoughts, intentions or feelings are. Another important function is shared attention. If a human being directs his/her gaze to a particular target or points towards it, a human observer is able to direct attention to the same target, understanding that both subjects are now sharing their attention. Dogs, probably because of domestication, are able to accomplish this very specific function but the great apes are not. Furthermore, human beings possess an unprecedented ability to generalize, to identify the common in the seemingly different and, therefore, are capable of forming abstract, symbolic representations. When monkeys learn to associate particular attributes with signals provided through one sensory modality, they usually have great difficulty recognizing the presence of the same attributes when signals are provided by a different modality. Humans accomplish such inter-modal transfer with great ease, probably because of the specific features of their cortical architecture that allow for easy exchange of information across the processing streams of the various sensory systems or because of the addition of association areas that allow for convergence of information from different modalities. The resulting ability of abstraction and symbolic coding is with all likelihood one of the prerequisites for the development of language. Other prerequisites seem to be the ability to represent complex sequences of nested relations which are at the origin of the comprehension and production of syntactic structures. Finally, human beings are capable of transmitting knowledge acquired during their lifetime through intentional instruction and education. Even the great apes learn essentially through imitation. Infant chimpanzees imitate nut cracking and even if they perform poorly, their mothers do not instruct their offspring but just continue to crack their own nuts.

This then raises the question of which changes in brain architecture might be responsible for the emergence of these novel cognitive abilities. When comparing the brains of the great apes with those of human beings, the only remarkable difference is the addition of new areas of the neocortex. Apart from that, there are no major structural changes and even the new cortical areas closely resemble with respect to their intrinsic organization those which exist both in humans and non-human primates. As outlined previously, the computational operations performed by a neuronal network are fully determined by its functional architecture and, therefore, it can be inferred that the new cortical regions operate according to the same principles as those that had already existed. Thus, the only options that these new areas offer are those that can be realized by implementing further nodes in the network. This could permit the generation of platforms for novel and more complex associations among the results obtained in parallel and previously unconnected processing streams or – if added on top of processing hierarchies – the generation of meta-representations. There is evidence for both strategies and both are likely foundations for the enhanced sophistication of human cognition. This interpretation agrees with the evidence that the molecular composition of nerve cells, the mechanisms mediating signal transduction and the molecular machinery supporting modification of synapses by learning closely resemble those found not only in all vertebrates but also in molluscs and insects. With the realization of the canonical circuits that characterize cortical modules, evolution has apparently discovered a computational algorithm that is universally applicable both to the evaluation of sensory signals of different modalities and to the design and organization of executive acts. Moreover, and this seems to be particularly advantageous, this canonical circuit can support iterative, reentrant processing of the results generated by these very circuits and thereby allow for the virtually unlimited recombination of signals.

EPIGENETIC SHAPING, CULTURAL DIVERSITY AND TOLERANCE

Together with anatomical modifications allowing bipedal gait that freed the front legs for duties other than locomotion, the development of the cognitive abilities listed above allowed *Homo sapiens* to initiate cultural evolution. Although at dramatically different time scales, the dynamics of biological and cultural evolution share certain similarities. In both cases, complexification and diversification of evolving structures were initially very slow but then experienced a dramatic acceleration. Once *Homo sapiens* appeared on stage, it took apparently tens of thousands of years to develop communication skills resembling syntactically based languages, social structures that allowed for labour sharing, tool making, sedentary lifestyles and the development of concepts that added a spiritual or metaphysical dimension to the material world. However, this period of slow differentiation underwent a phase transition about 30,000 years ago that led to an exponential acceleration of socio-cultural evolution with its countless ground breaking inventions. This acceleration suggests that evolutionary mechanisms that support autocatalytic processes became effective. One of them might have been the increase in population density. Increasing population density permitted the establishment of denser communication networks, the sharing of inventions, the development of cooperative strategies for a less time- and energy-consuming exploitation of resources and the reinvestment of the spared time and energy into exploratory activities that rendered these early societies more and more independent of the hazards of nature. However, the most effective factors that catalyzed this unprecedented acceleration are with all likelihood the extremely protracted postnatal development of the human brain and the ability of human subjects to intentionally educate their offspring. In conjunction, these two mechanisms make it possible to translate knowledge acquired during lifetime into the functional architecture of the brains of the respective offspring. As outlined above, these modifications consist of changes in circuitry that determine the functional architecture of brains in very much the same way as genes. Thus, although the basic blueprint of our brains is not very different from that of our cave dwelling ancestors as the genetic outfit has not changed much over the last 30,000 years, our brains differ from theirs because of epigenetic modifications that our brains experienced while developing in a highly complex socio-cultural environment.

Right from birth our brains are exposed to a much more complex environment than the brains of our ancestors because of the countless artifacts that the various cultures have invented and added to nature. Moreover, our children are exposed to highly sophisticated languages that convey not only factual knowledge but also the experience with complex relational structures. And finally, there is intentional education that sets in right after birth and is intensified until it occupies nearly the whole wake time as children grow older. Thus, through the combination of epigenetic modifiability of brain architectures with intentional education, a mechanism is introduced in the evolution of *Homo sapiens* that permits reliable transmission of knowledge acquired during lifetime to the subsequent generation.

This is not the place to analyze in detail similarities and differences between genetic and epigenetic modes of information transmission. However, there is one important difference that I would like to highlight because it has far reaching consequences for our concept of tolerance. The knowledge about the world that has been acquired during biological evolution and that governs our perception of the world is similar for all human beings and we share this knowledge in various degrees with the animal kingdom. Although different species have evolved into different ecological niches, the constraints to which cognitive systems had to adapt were rather similar. This is why we usually agree with respect to the perception of phenomena characterizing the precultural world. We share the inborn priors with other human beings and, therefore, as reflected by the similarity of the genetically determined features of our brain architectures, rightly assume that other human beings perceive the world in very much the same way as we do. Still it may occur in certain situations that subjects come to different conclusions concerning the perception of non-culture specific properties of objects. A color blind person for example bases her/his perception on different priors than a color competent subject. Both experience the same object in different ways and it would be hard for them to find out who is actually right. In this case, the dissent can be resolved by consulting 'objective measurement devices' and thereby including a third person perspective.

However, in case of the perception of realities that cultural evolution has generated, it is much less likely that all human beings agree. Priors installed by post-natal epigenetic shaping are much less likely to resemble each other than priors acquired during biological evolution. One of the hallmarks of cultural evolution is diversification. Accordingly, it is very likely that the priors acquired by early exposure to different cultures exhibit culture specific differences. As outlined above, the knowledge acquired during early development remains implicit because of childhood amnesia. Nevertheless, this implicit knowledge, just as the evolutionary acquired knowledge, will determine how subjects perceive the world around them. It follows from this that individuals raised in different cultures will base their perception on different epigenetically transmitted priors and, therefore, are likely to perceive realities, in particular those brought fourth by cultural evolution – the so-called social realities – in different ways. In situations where these perceptions are based on implicit priors, subjects will be absolutely convinced that the way in which they perceive a particular condition is the only way it can be perceived – just as we are convinced that there is only one way in which a particular object can be perceived. Subjects raised in different cultures with differing implicit priors about social realities will perceive the same social setting in perhaps very different ways, both experiencing their perceptions as evident and not questionable. However, in this case no 'objective measurement device' can be consulted. The categories of right and wrong become meaningless in this context. Both subjects have the same right to claim as correct what they perceive.

It is obvious that conflicts arising from diverging perceptions of the same social realities increase in frequency and severity as globalization forces different cultures to interact with each other. It is also obvious that the only recipe to cope with such conflicts is tolerance. However, the classical strategy to practice tolerance has been based on the implicit assumption that eventually a distinction between right and wrong is possible. If there is sufficient consensus about the perceived among members of a sufficiently large group of people, it is usually taken for granted that the respective perception of conditions is correct. Deviating perceptions of others are then considered as false and it is believed to be a tolerant attitude if the dissenting minority is allowed to continue to maintain its 'false beliefs' as long as these do not really challenge the system of the majority. However, as history has shown over and over again, this non-reciprocal concept of tolerance does not solve but generates problems because of its humiliating effect on the tolerated minority. The worldwide surge of terrorism is but one of the many deplorable consequences.

The scientific evidence on the dependence of perception on priors and on the acquisition of priors by epigenetic shaping of brain architectures forces us to adopt new concepts of tolerance that are based on strict reciprocity. Perceptions that are based on implicit priors cannot be changed by argument, they remain evident to the subject and resist relativism. In addition, when it comes to the perception of social realities, distinctions between right and wrong, between correct and false perceptions are impossible. Therefore, members of all cultures have to be credited that what they perceive is correct, even if the respective perceptions diverge. Thus, mutual recognition and reciprocal tolerance are required. Tolerance needs to be granted on a mutual basis and may only be withheld when the respective other violates the rules of reciprocal tolerance. These rules, in contrast to the differing perceptions of realities, are objectivatable and can be codified. Rather than attempting to defend belief systems based on idiosyncratic perceptions of social and cultural realities mankind, if it were to cope with the tremendous problems of globalization, will have to invest massively into the definition and defence of rules securing reciprocal tolerance.

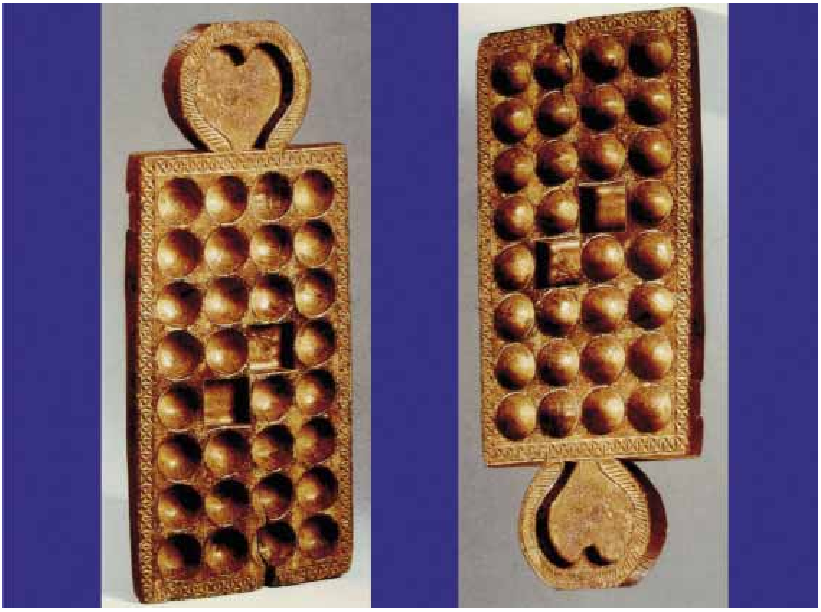

Figure 1.

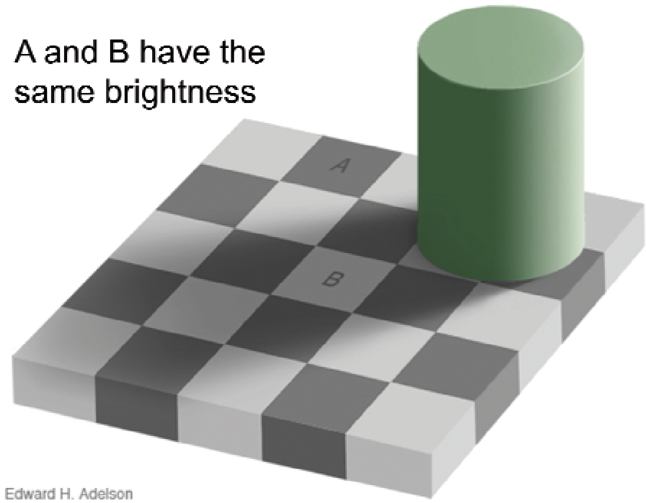

Figure 2.